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TITLE

BRUSH DC MOTORS AND AC COMMUTATOR MOTOR STRUCTURES WITH CONCENTRATED WINDINGS

BACKGROUND OF THE INVENTION

This invention relates to direct current motors or AC

5   commutator (Universal) motors. More particularly, this

invention relates to such motors which use a concentrated

winding on the rotor with coils wound around the teeth.

In conventional DC motors or AC commutator (Universal)

10   motors, there are three types of rotor armature windings:

lap windings, wave windings and frog-legs windings.

These windings are made with simple coil elements which

are always interlocked. With an interlocked winding, the

ratio between the axial length of the end-windings and

15   the axial length of the armature magnetic circuit is

relatively high as it is described by Klein U.S. Pat. No.

4,329610, Ban et al. U.S. Pat. No. 4,197,475 and Ikeda

U.S. Pat. No. 4,437,028.

All these windings differ primarily by the method which
is used to connect the terminals of the simple coils to
the commutator. A lap winding is also known as a multiple

5 winding and for this kind of winding the number of
parallel paths are equal to the number of poles. The wave
winding is sometimes called a series winding and it has
only two paths in parallel, regardless of the number of
poles. The frog-leg winding is the association of a lap

10 winding and a wave winding placed on the same armature,
in the same slots, and connected to the same commutator
bars.

The most significant problem with using a lap winding is

15 that the voltages induced in the different parallel paths
are unequal. These differences of induced voltages are
due to unequal magnetic circuit reluctances or unequal
fluxes under the different poles, which are created by
rotor eccentricity, misalignment of the poles, and/or

20 differences in permanent magnet magnetization. Because
of the imbalance in induced voltages, circulating
currents appear in the windings and through the brushes.
These circulating currents cause unnecessary heating of
the coils and brushes and tend to produce poor

25 commutation.

The use of equalizer connections is the common solution

to overcome the undesirable effects of circulating

currents. These connections improve the current

commutation and relieve the brushes of existing

5   circulating currents by providing low resistance paths

which by-pass the brush contacts. In a wave winding, the

problem of the circulating currents due to the unbalanced

voltages of the parallel paths is minimized but it is

also impossible to get perfectly balanced voltages.

10

To avoid the interlocking of the coils, it is possible to

directly wind the armature simple coils around each tooth

of the rotor magnetic circuit. This kind of winding is

called a concentrated winding, as described in our

15   scientific papers, "Permanent Magnet Brushless DC Motor

with Soft Metal Powder for Automotive Applications," IEEE

Industry Applications Society, St. Louis, Oct. 1998, and

"Synthesis of High Performance PM Motors with

'Concentrated Windings," IEEE IEMDC, Seattle, May 1999.

20   This kind of winding is also called a non-superposed

winding, as described by Ban et al. U.S. Pat. No.

4,197,475. This kind of winding reduces the copper

volume of the end-winding, the copper losses and the

total axial length of the motor. The efficiency is

25   improved when compared to the efficiency of classical

structures. This winding structure is also easier to

realize than a lap winding or a wave winding. When the axial length of the motor is small and the outside diameter of the motor is important, the use of such a winding structure allows a gain of 70% as compared to the

5   volume of copper used in an overlapped winding.

Rotor structures with a concentrated winding have a small number of slots and the magnetic circuit is easier to realize. The magnetic circuit can be realized with a

10   conventional soft magnetic laminated material (a yoke made of a stack of laminations) but it is also possible to use a soft magnetic composite material made of metal powder. The permeability of the soft magnetic composite is usually three times lower than the permeability of the

15   conventional laminated materials like it is described by Jack et al. W.O. Pat No. 99,50949. This low value of permeability reduces the value of the coil inductances in the armature and the commutation process in both collector and armature is improved. A rotor structure

20   with a small number of slots is also very well adapted to the realization of the armature magnetic circuit of direct current motors or ac commutator (Universal) motors with a soft magnetic composite material made of metal powder. With a small number of slots having relatively

25   large dimension, the mechanical constraints on the direct molding process of the rotor yoke are reduced. It is also

possible to easily insert the end-windings in the active part of the rotor magnetic circuit. This axial insertion of the end-windings improves the reduction of the volume of copper and the total axial length of the motor.

5   However, the concentrated winding technique is too often associated and restricted to windings with a short pitch, i.e. windings with lower performances than the performances of the classical winding structures. The

10   concentrated windings with a short pitch are then limited to sub-fractional power applications (lower than 100 W) such as used in electrical motors for computer peripherals or toys. This is the case for the simplest and low cost brush direct current motor, which is widely

15   used for toys. This 2-pole motor uses permanent magnets on the stator core, and has three teeth on its rotor core and a concentrated winding with one coil only wound around each tooth. The armature coil terminals are connected to a commutator with three segments and two

20   brushes, as described by Fujisaki et al. U.S. Pat. No. 4,868,433. This structure has a winding with a short pitch of 120 electrical degrees. The winding coefficient or the ratio between the fundamental component of magnetic flux embraced by the winding and the total

25   magnetic flux per pole is only equal to 0.866.

The main drawbacks of this motor structure are its low performance in terms of torque to weight ratio, torque ripple, and poor commutation performance if the power is increased. With this structure, the induced voltages in the coil paths between brushes are not always balanced. This unbalanced condition of operation produce supplementary losses, torque ripples, mechanical vibrations and commutation problems. These problems are acceptable for low power applications only.

SUMMARY OF THE INVENTION

This invention is an armature winding of a DC or AC commutator motor, which eliminates the problem of the interlocking of the coils and the problem of circulating currents. All the path voltages are perfectly balanced and the current commutation is improved when compared to the classical structures.

In this invention, the number of commutator segments is higher than the number of rotor teeth, and a plurality of simple coils are wound around the same tooth. The leads of each coil are connected to different segments of the commutator. Use of the present invention reduces the number of turns per coil for a same value of the DC voltage supply and a same speed range of the motor. The

parallel paths of the armature winding can be perfectly

balanced. An equal current distribution through the

parallel circuits of the armature is maintained and there

is no circulation current between these parallel

5   circuits. The inductance value of each simple coil is

reduced and consequently the commutation problems are

minimized when compared to the case of a concentrated

winding with only one coil wound around each tooth. The

copper volume of the end-windings, the Joule losses and

10   the axial length of the motor armature are lower than in

the case of a lap or a wave winding with interlocking

coils. It is also possible to arrange connections of the

leads of each coil to the commutator segments to obtain

balanced emf in the different coil paths between brushes.

15   These structures can be used efficiently for motors over

a wide range of power, and their cost of realization is

lower than the cost of classical structures.

In accordance to this invention, two kinds of structures

20   are presented: structures with a regular distribution of

rotor teeth with identical dimensions, and structures

with a regular distribution of rotor teeth with different

dimensions. Both structures are efficient in terms of

performance and cost of realization. The values of the

25   winding coefficients of these structures (i.e. the ratio

between the fundamental component of magnetic flux

embraced by the winding and the total magnetic flux per

pole) are high.

5   The performance of the structures proposed in accordance

with the present invention is similar to the performance

of the classical structures in terms of current

commutation. But the performance of the structures

proposed in accordance with the present invention in

10   terms of torque to winding volume ratio is higher than

the performance of the classical structures. With the

proposed structures, the volume of copper is reduced, the

Joules losses (copper losses) and the weight are

minimized. The total axial length of the motor is

15   reduced. The efficiency is improved and is higher than in

the case of classical structures. The structures of the

winding and the magnetic circuit, which are proposed in

accordance with the present invention, are also easier to

realize. The total cost of the motor is then minimized.

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BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a cross-sectional view of an example of a

direct current motor with a concentrated winding and

permanent magnets in accordance with the present
invention.

Figure 2 is a diagram of a developed surface of a drum
5   armature, made by unrolling the periphery of the armature
and commutator into a plane.

Figure 3 is a diagram of construction of a machine
equivalent to the machine of Fig. 2 with a rotor winding
10   made of concentrated windings wound around the teeth.

Figure 4 is a developed diagram of a machine with 3 rotor
slots, 2 stator poles, 6 commutator segments and 2
brushes with a rotor winding made of concentrated
15   windings wound around the teeth.

Figure 5 is a developed diagram of a machine with 6 rotor
slots, 4 stator poles, 12 commutator segments and 4
brushes with a rotor winding made of concentrated
20   windings wound around the teeth.

Figure 6 is a developed diagram of a machine with 6 rotor
slots, 4 stator poles, 12 commutator segments and 2
brushes with a rotor winding made of concentrated
25   windings wound around the teeth.

Figure 7 is a diagram of a machine with 20 rotor slots, 4 stator poles, 20 commutator segments, 4 brushes with a simplex lap winding and a short pitch from 1 to 5.

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Figure 8 is a diagram of construction of a machine equivalent to the machine of Fig. 7 with a rotor winding made of concentrated windings wound around the teeth.

10   Figure 9 is the diagram of a machine with 5 rotor slots, 4 stator poles, 20 commutator segments and 4 brushes with a rotor winding made of concentrated windings wound around the teeth.

15   Figure 10 is a diagram of the parallel coils paths of the machines presented in Fig. 7 and Fig. 9.

Figure 11 is a developed diagram of a machine with 5 rotor slots, 4 stator poles, 20 commutator segments and 2

20   brushes with a rotor winding made of concentrated windings wound around the teeth.

Figure 12 is a developed diagram of a machine with 5 rotor slots, 4 stator poles, 40 commutator segments and 4

brushes with a rotor winding made of concentrated

windings wound around the teeth.

Figure 13 is a developed diagram of a machine with 5

5   rotor slots, 4 stator poles, 40 commutator segments and 2

brushes with a rotor winding made of concentrated

windings wound around the teeth.

Figure 14 is a developed diagram of a machine with 10

10   rotor slots, 8 stator poles, 40 commutator segments and 8

brushes with a rotor winding made of concentrated

windings wound around the teeth.

Figure 15 is a developed diagram of a machine with 12

15   rotor slots, 4 stator poles, 12 commutator segments, 4

brushes with a simplex lap winding and a diametral pitch.

Figure 16 is a diagram of construction of an equivalent

machine of Fig. 15 with a rotor winding made of

20   concentrated windings wound around the teeth.

Figure 17 is a developed diagram of a machine with 6

rotor slots, 4 stator poles, 12 commutator segments and 4

brushes with a rotor winding made of concentrated

25   windings wound around the teeth.

Figure 18 is a developed diagram of a machine with 6

rotor slots, 4 stator poles, 12 commutator segments, 2

brushes with a rotor winding made of concentrated

5   windings and a regular distribution of rotor teeth with

two different dimensions.

Figure 19 is a developed diagram of a machine with 10

rotor slots, 8 stator poles, 40 commutator segments, 4

10   brushes with a rotor winding made of concentrated

windings and a regular distribution of rotor teeth with

two different dimensions.

Figure 20 is the axial sectional view of a permanent

15   magnet motor with a rotor magnetic circuit realized with

a laminated steel material.

Figure 21 is the axial sectional view of a permanent

magnet motor with a rotor magnetic circuit realized with

20   an isotropic soft magnetic composite material.

Figure 22 is the axial sectional view of a motor with a

rotor magnetic circuit realized with an isotropic soft

magnetic composite material.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

In one embodiment of the present invention, the rotor has a regular distribution of rotor teeth with identical

5   dimensions, and there are 2P poles, magnetized alternatively North and South in the stator. These poles can be constructed with segments of permanent magnet mounted on the surface of a core made of soft magnetic material or with coils wound around teeth made of soft

10   magnetic material and fed by a DC or AC current. The rotor core has S slots. The simple coils of the rotor are wound around S teeth or in some case around S/2 teeth only. There are Z segments on the commutator which are connected to the terminals of the coils. 2B brushes are

15   sliding on the commutator surface when the rotor is rotating. The characteristics of these machines respect the following conditions:

20
3

P is an integer and $0 < P < 10$

$S = 2P + A$ A is an integer equal to -1 or 1 or 2 or

$S > 2$

$Z = k*LCM(S,2P) \pm n$ k is an integer greater than 0

25   LCM is the Least Common Multiple of S and 2P

                n is equal to 0 or k

$B = P$ or less

30

Table 1 hereto presents some structures which respect these conditions with k equal to 1 and n equal to 0. The

number of coils per path is equal to mph (mph= Z/2P). The

number of brushes 2B is normally equal to the number of

stator poles 2P. Several concentric coils are wound

around each rotor tooth and are connected on different

5 commutator segments. In this case, the number N of

concentric coils per tooth is equal to:

$$N = z/s$$

10

With this winding configuration, a reduction of the

number of turns per simple coil is obtained. The same

reduction of the number of turns is usually obtained in a

classical machine structure with the same number of

15 stator poles by employing a higher number of rotor slots.

Because the inductance value of each simple coil is

reduced, commutation problems are minimized.

It is also possible to arrange the connections of each

20 coil to the commutator segments to obtain balanced emf's

in the different coil paths between brushes. Such

structures can have a value of winding coefficient Kb

(ratio between the fundamental component of magnetic flux

embraced by the winding and the total magnetic flux per

25 pole) near to 1 (table 1) and consequently a high torque-

weight ratio. All these machines can be used efficiently

for motors and generators over a wide range of power and

for high levels of armature current.

2P	2	4	4	6	6	6	8	8	8	10	12
S	3	5	6	5	7	8	7	9	10	12	15
Z=LCM(S,2)	6	20	12	30	42	24	56	72	40	60	60
Mph= Z/2P	3	5	3	5	7	4	7	9	5	6	5
2B	2	4	4	6	6	6	8	8	8	10	12
N	2	4	2	6	6	3	8	8	4	5	4
Kb	0.866	0.951	0.866	0.951	0.975	0.924	0.975	0.984	0.951	0.965	0.951

Table 1

It is additionally possible to reduce the number of

brushes 2B and also the number N of concentric coils

which are wound around the same rotor tooth to minimize

the cost of the motor. Motors having such a structure

are presented in table 2. The structures listed in

column 2 to 11 of table 1 present this characteristic.

It is then necessary to add some equalizer connections on

the commutator segments (wires which directly connect

segments without lying in the slots, see for example wire

conecting segment 3 to 9 in Figure 6). It should be

noted that this modification decreases the performance of

the commutation process, while increasing the level of

current in the remaining brushes. This kind of

modification is preferably utilized in sub-fractional and

fractional power machines.

2P	2	4	4	6	6	6	8	8	8	10
S	3	5	6	5	7	8	7	9	10	12
Z=LCM(S,2P)	6	20	12	30	42	24	56	72	40	60
mph= Z/2P	3	5	3	5	7	4	7	9	5	6
2B	2	2	2	2	2	2	2 or 4	2 or 4	2	2
N	2	2, 4	1, 2	2, 6	2, 6	1, 3	2, 4, 8	2, 4, 8	2, 4	1, 5
Kb	0.866	0.951	0.866	0.951	0.975	0.924	0.975	0.984	0.951	0.965

Table 2

5   It is also possible to reduce the number of commutator
segments Z by two and to apply the following relations to
determine the number of segments:

$$Z = LCM(S,2P)/2 \qquad \text{and} \qquad Z/2P > 3$$

10

With this reduction of the number of segments, as in the
structures presented in table 3, one obtains an
unbalanced emf in the different coil paths between
15   brushes, with the level of this unbalance being inversely
proportional to the
number of coils in each parallel path.

2P	4	6	6	8	8	8	10	12	12
S	5	5	7	7	9	10	11	11	15
Z=LCM(S,2P)/2	10	15	21	28	36	20	55	66	30
2mph= Z/2P	5	5	7	7	9	5	11	11	5
2B	4	6	6	8	8	8	10	12	12
N	2	3	3	4	4	2	5	6	2
Kb	0.951	0.951	0.975	0.975	0.984	0.951	0.990	0.990	0.951

20   Table 3

In a second embodiment of the present invention, the
rotor of these structures presents a regular distribution
of rotor teeth with different dimensions.

5   In particular, the stator of these machines have 2P poles
magnetized alternatively North and South. These poles can
be realized with permanent magnet segments mounted on the
surface of a core made of soft magnetic material, or with
coils wound around teeth made of soft magnetic material

10   and fed by a DC or AC current. The rotor core has S slots
and rotor teeth of two different geometrical dimensions,
which alternate around the circumference of the core.
The rotor coils are wound around S/2 teeth. There are Z
segments on the commutator which are connected to the

15   terminals of the coils. 2B brushes slide on the
commutator surface when the rotor is rotating. The
characteristics of these machines respect the following
conditions:

20   P is an integer and $1 < P < 10$
                       S = 2P + 2A   A is an integer and $1 < A < P$
                       Z = k*LCM(S/2,2P) $\pm$ n   k is   an integer greater than 0
                                         LCM is the least Common 1
                                         Multiple of S/2 and 2P
25   n is equal to 0 or k

                       B = P   or less

30   Table 4 herein provides exemplary structures which
respect these conditions, with k equal to 1 and n equal

to 0. The number of coils per path is equal to mph (mph= Z/2P). The number of brushes 2B is normally equal to the number of stator poles 2P. Several concentric coils are wound around each rotor tooth and are connected on

5 different commutator segments. In this case, the number N of concentric coils

wound around each rotor tooth is equal to:

$$N = 2Z/S$$

10

2P	4	6	6	8	8	8	10	10	10	10
S	6	8	10	10	12	14	12	14	16	18
Z=LCM(S/2,2P)	12	12	30	40	24	56	60	70	40	90
mph= Z/2P	3	4	5	5	3	7	3	7	4	9
2B	4	6	6	8	8	8	10	10	10	10
N	4	3	6	8	4	8	10	10	5	10
Kb	1	1	1	1	1	1	1	1	1	1

Table 4

15 These motor structures offer the same advantages of the previous ones listed in table 1 in terms of current commutation performance and balanced parallel coils path. But it is also possible to get a higher winding coefficient Kb (equal to unity, Kb=1), and to maximize

20 the torque per unit of volume of copper. These structures can be used efficiently for motors and generators over a wide power range and for high levels of armature current. It is also possible, as in the case of the previous structures of table 1, to apply different simplifications

25 for the choice of the number of brushes, the number

commutator segments and the number of concentric coils

per tooth to reduce the cost of the motor and simplify

the realization.

5   It must be noticed that all the proposed solutions which

are in accordance with the present invention can be used

with different brush widths.

According to the present invention, a DC or AC commutator

10   motor can be manufactured with a magnetic circuit made of

laminated steel or made of a soft magnetic composite

material.

In particular, when an isotropic soft magnetic composite

15   is used, a portion of the magnetic flux can also

circulate in the axial direction. For this reason, it is

possible to expand the tooth tips in the axial direction,

and thus maximize the axial length of the active air-gap

area for a given total axial length of the motor as fixed

20   by the specifications of the application. In such

structures, the air-gap flux is concentrated into the

center part of the rotor teeth under the coils and the

yoke. Because the axial length of the center part of the

rotor teeth under the coils and the axial length of the

25   yoke is smaller than the axial length of the tooth tips,

the end-windings, the commutator and the brushes are now

axially inserted and the total axial length of the motor

is reduced. With this method, the isotropic properties

of the soft magnetic composites are used to minimize the

5   axial length of a motor without reducing the torque

performance.

When an isotropic soft magnetic composite is used, the

cross-section profile of the center part of the rotor and

10   stator teeth under the coils can be made round, oval, or

circular. These profiles can reduce the risk of

destruction of the insulation by a sharp bending of the

winding coils, and maximize the copper filling factor.

15   It is also possible to skew the permanent magnets or the

teeth of the stator to reduce the variations of the air-

gap reluctance or the cogging torque. The same result can

be obtained by skewing the teeth of the rotor. When an

isotropic soft magnetic composite is used, it is possible

20   to skew only the tooth tips.

FIG 1 shows a cross-sectional view of an example of a

direct current motor with a concentrated winding and

permanent magnets in accordance with the present

25   invention. Part 1 is the yoke of the stator. Part 2 is

~~one of the stator poles, which are magnetized~~ alternatively North and South, and which is made of a segment of permanent magnet. Part 3 is the tip of a rotor tooth. Part 4 is the center part of the rotor tooth under

5   the coils. Part 5 is the yoke of the rotor. Part 6 is the concentrated winding, wound around a stator tooth. Part 7 is one of the segments or bars of the commutator. Part 8 is one of the brushes in contact with the segments of the commutator and which is used to feed the supply current

10   ~~to the armature winding.~~

Figures 2, 3 and 4 each illustrates a method to derive the structure of a machine with a rotor winding made of concentrated windings wound around the teeth from the

15   structure of a classical machine. Each of these structures presents the same number of stator poles, and a commutator segment number equal to the rotor slot number.

20   More particularly, figure 2 shows a classical structure with 6 rotor slots, 2 stator poles, 6 segments on the commutator and 2 brushes. The winding of the rotor is a simplex lap winding, overlapped with a short pitch of 120 electric degrees. The connections of the terminals of

25   each simple coil to the segments of the commutator are

arranged to get coils paths perfectly balanced in the

armature winding.

In Figure 2, the 6 simple coils of the armature winding

5   are denoted 1.1, 1.2, 2.1,2.2,3.1,3.2. Coils 1.1 and 1.2

denote simple coils which have the same phase of emf,

because their positions relative to the stator poles are

identical. The same is the case with coils 2.1, 2.2, and

with coils 3.1, 3.2. The dots in Figure 2 are polarity

10   marks and indicate the polarity of the winding, in

accordance with standard notation in the art. The teeth

defining the 6 rotor slots are defined by T1 through T6,

respectively. The commutator segments are labeled 1

through 6 respectively, and as can be seen, a voltage V

15   is applied to the brushes B1, B2. The north and south

stator poles are labeled N and S, respectively. Similar

nomenclature is used in the balance of the figures.

In comparison with Figure 2, by regrouping simple coils

20   which have the same phase of emf on the same tooth of the

rotor, one avoids the interlocking of the end-windings,

as is shown on figure 3. More particularly, FIG 3 is a

diagram of construction of a machine equivalent to the

machine of fig 2 in terms of torque and emf

25   characteristics, magnetic flux and current density, where

the rotor winding in Figure 3 is made of concentrated

windings around the teeth. The simple coils having emf's

which are in phase as coils 1.1 and 1.2 in Fig. 2 are

regrouped on a same tooth. To increase the size of the

5   slots filled with conductors and to preserve the same

total copper section of the whole rotor armature in the

original machine of Fig. 2 and in the equivalent machine

of Fig. 3 (i.e. the sum of the copper section of each

slot), the teeth around the empty slots are regrouped to

10   form the new distribution of teeth presented in Fig. 3.

As compared to Fig. 2, the position of the tooth tips in

Figure 3 are not modified at the level of the airgap;

however the center parts of the teeth of the machine of

Fig. 2 between the tooth tips and the inner rotor yoke

15   have been shifted in Figure 3 to form a single big tooth.

With this method, the pattern of the no-load magnetic

flux spatial distribution in the airgap is not modified

and the total section of the soft magnetic material in

the teeth from the original machine of Fig. 2 to the

20   equivalent machine of Fig. 3 is also preserved to avoid a

saturation of the magnetic flux. Therefore the total

amounts of soft magnetic material in the yoke and copper

in the slots are modified as well. One gets a machine

with a concentrated winding presented in Fig. 3 which is

25   equivalent to the initial machine of Fig. 2, as explained

above. The shape and the emf amplitude in each coil are
not modified.

As shown in Figure 3, some slots are empty and it is
5   possible to group teeth around each empty slot. The
position of the tooth tips are not modified at the level
of the airgap, only the center parts of the teeth between
the tooth tips and the inner rotor yoke are shifted to
form a single big tooth. The pattern of the no-load
10   magnetic flux spatial distribution in the airgap is not
modified, as is shown in figure 3. One can then
concentrate the simple coils around each tooth. The
total section of soft magnetic material in the teeth and
the total copper section of the whole rotor armature are
15   preserved and are identical to the corresponding sections
in the initial machine with a classical structure.

FIG 4 is a developed diagram of a machine with 3 rotor
slots, 2 stator poles, 6 commutator segments and 2
20   brushes with a rotor winding made of concentrated
windings wound around the teeth. Two simple coils, like
coils 1.1 and 1.2, are wound around the same tooth and
are connected to different segments of the commutator.
The connections to the commutator segments are identical
25   to the connections used in the machine shown in Fig 2.

One can notice on the diagram on the right that the coils

paths are not modified. Each simple coil wound around a

same tooth like coil 1.1 and coil 1.2 has an identical

emf. The total emf's across each parallel coil path are

5   now perfectly balanced, even if the airgap reluctances or

the magnetization of the permanent magnets under each

pole of the stator are not perfectly identical. This

machine is equivalent to the machine presented in Fig 2

in terms of torque and emf characteristics, magnetic flux

10 density and current density.

The machine presented on the figure 4 has a concentrated

winding, which is equivalent to the initial machine of

Fig.2, in terms of torque and emf characteristics,

15 magnetic flux and current density. The connections of the

terminals of the simple coils to the commutator are

identical in both machines (i.e. machines on Fig 2 and

Fig 4). The coil paths in the armature winding are always

balanced: i.e. the total emf's across each parallel coil

20 path are balanced, even if the airgap reluctances or the

magnetization of the permanent magnets under each pole of

the stator are not perfectly identical.

FIG 5 is a developed diagram of a machine with 6 rotor

25 slots, 4 stator poles, 12 commutator segments and 4

brushes with a rotor winding made of concentrated windings wound around the teeth. This machine is derived from the machine presented in the fig 4 by doubling the periodicity of its structure.

5

In addition, several modifications can be realized to simplify these structures in the case of a sub-fractional power machine made in accordance to the present invention. In particular, it is possible to reduce the

10 number of brushes while adding equalizer connections on the commutator. This is shown in Figure 6, which is a developed diagram of a machine with 6 rotor slots, 4 stator poles, 12 commutator segments and 2 brushes with a rotor winding made of concentrated windings wound around

15 the teeth. This machine is an evolution of the machine presented in Fig 5 with a reduced number of brushes and with equalizer connections added on the commutator. It can be seen in Figure 6 that the two coils wound around each tooth are connected in parallel by equalizer

20 connections. Optionally, one could reduce the number of simple coils around each tooth to one, with several of the commutator segments not being directly connected to coil terminals.

The same method is applied on figures 8 and 9 for another

example, in accordance to the present invention.

Initially figure 7 depicts a classical machine having 20

rotor slots, 4 stator poles, 20 segments on the

5   commutator and 4 brushes. The winding of the rotor is

overlapped with a short pitch of 1 to 5. The coil paths

in the armature winding are presented on fig. 10.

FIG 8 is a diagram of the construction of a machine

10   equivalent to the machine of fig 7 in terms of torque and

emf characteristics, magnetic flux and current density,

with the rotor winding in Fig. 8 made of concentrated

windings wound around the teeth. The coils having emf's

which are in phase as coils 1.1, 1.2, 1.3, 1.4 are

15   regrouped on a same tooth. To increase the size of the

slots filled with conductors and to preserve the same

total copper section of the whole rotor armature in the

original machine of Fig.7 and in the equivalent machine

of Fig.8 (i.e. the sum of the copper section of each

20   slot), the teeth around the empty slots are regrouped to

form the new distribution of teeth presented in Fig.8.

The position of the tooth tips are not modified at the

level of the airgap, only the center parts of the teeth

of the machine of Fig.7 between the tooth tips and the

25   inner rotor yoke have been shifted to form a single big

tooth. With this method, the pattern of the no-load

magnetic flux spatial distribution in the airgap is not

modified. The total section of soft magnetic material in

the teeth from the original machine of Fig.7 to the

5   equivalent machine of Fig.8 is also preserved to avoid

saturation of the magnetic flux. Therefore the total

amounts of soft magnetic material in the yoke and copper

in the slots are not modified as well. One gets a machine

with a concentrated winding presented in Fig.8 which is

10   equivalent to the initial machine of Fig.7, as explained

above. The shape and the emf amplitude in each coil are

not modified.

FIG 9 is the diagram of a machine with 5 rotor slots, 4

15   stator poles, 20 commutator segments and 4 brushes with a

rotor winding made of concentrated windings wound around

the teeth. Four simple coils are wound around a same

tooth and are connected to different segments of the

commutator. Connections to the commutator segments are

20   identical to the connections used in the machine

presented on the Fig 7. Each simple coil wound around a

same tooth, like coils 1.1 and 1.2 and 1.3 and 1.4, has

an identical emf. The total emf's across each parallel

coil path (fig 10) are now perfectly balanced, even if

25   the airgap reluctances or the magnetization of the

permanent magnets under each pole of the stator are not

perfectly identical. This machine is equivalent to the

machine presented in Fig 7 in terms of torque and emf

characteristics, magnetic flux density and current

5   density.

FIG 10 is a diagram of the parallel coils paths of the

machines presented in fig 7 and fig 9.

10   Several modifications can be realized to simplify these

structures in the case of a sub-fractional power machine

in accordance to the present invention. It is possible

to reduce the number of brushes while adding equalizer

connections on the commutator. One can also reduce the

15   number of simple coils as it is presented on the figure

11. In accordance to the present invention, figure 12

shows the same kind of motor as is depicted in Fig. 9

with a higher periodicity of structure.

20   More particularly, FIG 11 is a developed diagram of a

machine with 5 rotor slots, 4 stator poles, 20 commutator

segments and 2 brushes with a rotor winding made of

concentrated windings wound around the teeth. This

machine is an evolution of the machine presented in the

25   fig 9 with a reduced number of brushes and equalizer

connections are added on the commutator. In this

machine, it is also possible to reduce the number of

simple coils on each tooth to 2 as is shown in Figure 11.

5   Likewise, FIG 12 is a developed diagram of a machine with

5 rotor slots, 4 stator poles, 40 commutator segments and

4 brushes with a rotor winding made of concentrated

windings wound around the teeth. This machine is an

evolution of the machine presented in the fig 9 with a

10   higher number of simple coils and number of commutator

segments.

Figure 13 shows the same structure of motor presented on

fig 9 with a higher number of commutator segments and a

15   higher simple coil number wound around a tooth, in

accordance with the present invention.

More particularly, FIG 13 is a developed diagram of a

machine with 5 rotor slots, 4 stator poles, 40 commutator

20   segments and 2 brushes with a rotor winding made of

concentrated windings wound around the teeth. This

machine is an evolution of the machine presented in the

fig 12 with a reduced number of brushes and equalizer

connections added on the commutator. The number of

25   segments between 2 brushes of inverse polarity (+ and -)

is increased according to the solution presented with respect to fig 9 (10 segments vs. 5 segments). Therefore, the voltage between 2 successive segments is lower.   This kind of solution is of utility when the

5   supply voltage is high and it permits limiting the amplitude of the voltage between 2 successive segments. It is possible to reduce the number of simple coils on each tooth to 2 in this figure.

10   Figure 14 is an evolution of the solution presented on figure 9, in accordance to the present invention, with a higher periodicity of the structure.

More particularly, FIG 14 is a developed diagram of a

15   machine with 10 rotor slots, 8 stator poles, 40 commutator segments and 8 brushes with a rotor winding made of concentrated windings wound around the teeth. This machine is derived from the machine presented in the figure 9 by doubling the periodicity of its structure.

20

The present invention is applied on figures 16 and 17, which depict a machine with a rotor winding made of concentrated windings and a regular distribution of rotor teeth with two different dimensions.   The classical

25   machine for reference presented in figure 15 has 12 rotor

slots, 4 stator poles, 12 segments on the commutator and 4 brushes. The winding of the rotor is overlapped with a diametral pitch.

5   FIG 16 is a diagram of construction of an equivalent machine of fig 15, in terms of torque and emf characteristics, magnetic flux and current density, with the rotor winding in Figure 16 made of concentrated windings wound around the teeth. The coils having emf's

10   which are in phase as coils 1.1, 1.2, 1.3, 1.4 are regrouped on a same tooth. To increase the size of the slots filled with conductors and to preserve the same total copper section of the whole rotor armature in the classical machine of Fig.15 and in the equivalent machine

15   of Fig.16 (i.e. the sum of the copper section of each slot), the teeth around the empty slots are regrouped to form the new distribution of teeth presented in Fig.16. The position of the tooth tips are not modified at the level of the airgap, only the center parts of the teeth

20   of the machine of Fig.15 between the tooth tips and the inner rotor yoke have been shifted to form a single big tooth. With this method, the pattern of the no-load magnetic flux spatial distribution in the airgap is not modified. The total section of soft magnetic material in

25   the teeth from the original machine of Fig.15 to the

equivalent machine of Fig.16 is also preserved to avoid a

saturation of the magnetic flux. Therefore the total

amounts of soft magnetic material in the yoke and copper

in the slots are not modified as well. One can notice

5   that all the coils are wound around 3 teeth only. One

gets a machine with a concentrated winding presented in

Fig.16 which is equivalent to the initial machine of

Fig.15, as explained above. The shape and the emf

amplitude in each coil are not modified.

10

FIG 17 is a developed diagram of a machine with 6 rotor

slots, 4 stator poles, 12 commutator segments and 4

brushes with a rotor winding made of concentrated

windings wound around 3 teeth. There is a regular

15   distribution of rotor teeth of two different dimensions,

with teeth T1, T2 and T3 of one dimension, and teeth T4,

T5 and T6 of a second dimension. Four simple coils are

wound around each tooth and are connected to different

segments of the commutator. The connections to the

20   commutator segments are identical to the connections used

in the machine presented on the Fig 15. The coils paths

are perfectly balanced. This machine is equivalent to

the machine presented in Fig 15 in terms of torque and

emf characteristics, magnetic flux density and current

25   density, with a winding coefficient equal to 1. The

performance of this kind of concentrated winding machine
is high.

In the case of a sub-fractional power machine constructed

5   in accordance with this invention, several modifications

can be made to simplify the structure. For example, it

is possible to reduce the number of brushes while adding

equalizer connections on the commutator. FIG 18 is a

developed diagram of a machine with 6 rotor slots, 4

10   stator poles, 12 commutator segments, 2 brushes with a

rotor winding made of concentrated windings and a regular

distribution of rotor teeth with two different

dimensions. This machine is an evolution of the machine

presented in the fig 17 with a reduced number of brushes

15   and equalizer connections added on the commutator. In

this machine, it is also possible to reduce the number of

simple coils on each tooth to 2 as is shown in Figure 18.

Figure 19 presents the result of another example of a

20   machine with a rotor winding made of concentrated

windings and a regular distribution of rotor teeth with

two different dimensions. The initial machine has 40

rotor slots, 8 stator poles, 40 segments on the

commutator and 8 brushes. The equivalent machine, in

25   accordance to the present invention, has 10 rotor slots

with rotor teeth of two different geometrical dimensions (teeth T1 through T5 being of one dimension, and T6 through T10 being of a second dimension), 8 stator poles, 40 segments on the commutator and 4 brushes. There are 8

5 simple coils per tooth. Connections of the simple coils on the commutator are the same as the initial machine. It is possible to reduce the number of brushes while adding equalizer connections on the commutator.

10 FIG 20 is an axial sectional view of a permanent magnet motor with a rotor magnetic circuit realized with a laminated steel material. Usually, the axial dimension of the magnetic circuit of the rotor (parts 3, 4, 5) is lower than the axial length of the permanent magnet. The

15 flux of the permanent magnets is thus concentrated axially into the rotor and it is possible to insert, partially, the end-winding under the permanent magnets axial length. This modification of the axial dimension of the rotor reduces the total axial length of the motor.

20

FIG 21 is the axial sectional view of a permanent magnet motor with a rotor magnetic circuit realized with an isotropic soft magnetic composite material. In an isotropic magnetic material, a portion of the magnetic

25 flux can also circulate in the axial direction. It is

therefore possible to increase the flux concentration without decreasing the performance of the motor. The center part of the rotor teeth under the coils (part 4) and the rotor yoke (part 5) have the same axial dimension

5 and the tips of the teeth (part 3) have an axial dimension nearly identical to the axial length of the permanent magnets. The total axial length of the motor is reduced when compared to a rotor with a laminated steel (fig 20). It is then possible with this structure

10 to maximize the axial length of the active air-gap area for a total axial length fixed by the specifications of the application.

FIG 22 is the axial sectional view of a motor with a

15 rotor magnetic circuit realized with an isotropic soft magnetic composite material. The structure presented on figure 22 is an evolution of the structure of the fig 21. The center part of the rotor teeth under the coils (part 4) and the rotor yoke (part 5) have the same axial

20 dimension and the tips of the teeth (part 3) have an axial dimension nearly identical to the axial length of the permanent magnets. Part 4 and part 5 are shifted axially. The end-windings, commutator and brushes are inserted partially or totally in the axial direction for

a further minimization of the total axial length of the motor.

The proposed motor structures of this invention are very
5 well adapted to the realization of the rotor magnetic
circuit with a soft magnetic composite material made of
metal powder. With a small number of slots with
relatively large dimensions, the mechanical constraints
on the direct molding process of the rotor yoke are
10 reduced. An isotropic soft magnetic composite is also
well adapted to realize an axial air-gap flux
concentration in the rotor or the stator magnetic circuit
and to reduce the total axial length of the motor without
decreasing the performances of motor. The tips of the
15 teeth can be expanded axially and used to concentrate the
magnetic flux in the airgap, axially, into the teeth and
the yoke of the rotor or the stator (fig 21 & 22). The
axial length of the tips of the rotor teeth can have an
axial dimension nearly identical to the axial length of
20 the permanent or the axial length of the tooth tips of
the stator. The axial dimension of the teeth and the yoke
are the same and can be lower than the axial dimension of
the tooth tips (fig 21 & 22). The center part of the
rotor teeth under the coils and the rotor yoke can also
25 be decentered and shifted axially (fig 22). It is also

possible to axially insert the end-windings inside the

tooth tips (fig 21 & 22). The commutator and the brushes

can also be inserted partially or totally in the axial

direction under the rotor tooth tips (fig 22). This kind

5   of structure has utility in reducing the total axial

length of the motor.

~~When an isotropic soft magnetic material is used, it is~~

also useful to make the cross-section profile of the

10   center part of the rotor and stator teeth under the

coils, round, oval, or circular to get a reduction of the

risk of destruction of the insulation by a sharp bending

of the winding coils, and to maximize the copper filling

~~factor.~~

15

All the embodiments of this invention can be used with

different brush widths. The rotor slots and/or the stator

slots can be skewed to reduce the variations of the

magnetic reluctance. In the case of a stator with

20   permanent magnets, it is also possible to skew the rotor

slots and/or the permanent magnets to reduce the cogging

torque. When an isotropic soft magnetic composite is

used, it is possible to skew only the tips of the rotor

teeth and/or the tips of the stator teeth.

25

The new structures of DC and AC commutator motor of the present invention can be used in a large variety of applications (automotive applications, electrodomestic appliances, corded electric tools, electric vehicles,

5   fractional and sub-fractional DC and AC commutator motors, etc.). The improved efficiency and the simplifications realized on the rotor winding will provide a lower realization cost and higher performances than classical structures.

10

While only some embodiments of the present invention are described above, it is obvious that several modifications or simplifications are possible without departing from

15   the spirit of the present invention. Thus, the invention may be applied to motors with a radial airgap or tranversal airgap. Also, the invention can be used in machines having an inner rotor or an outer rotor structure. It is also understood that various further

20   changes and modifications can be made without departing from the spirit and scope of the invention.